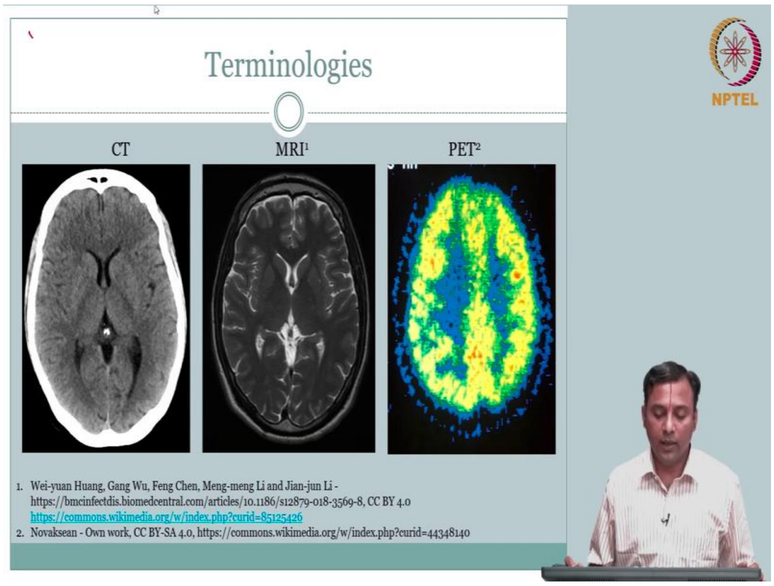
Introduction to Biomedical Imaging Systems
Dr. Arun K. Thittai
Department of Applied Mechanics
Indian Institute of Technology, Madras

Lecture - 03
Introduction - 02

(Refer Slide Time: 00:14)



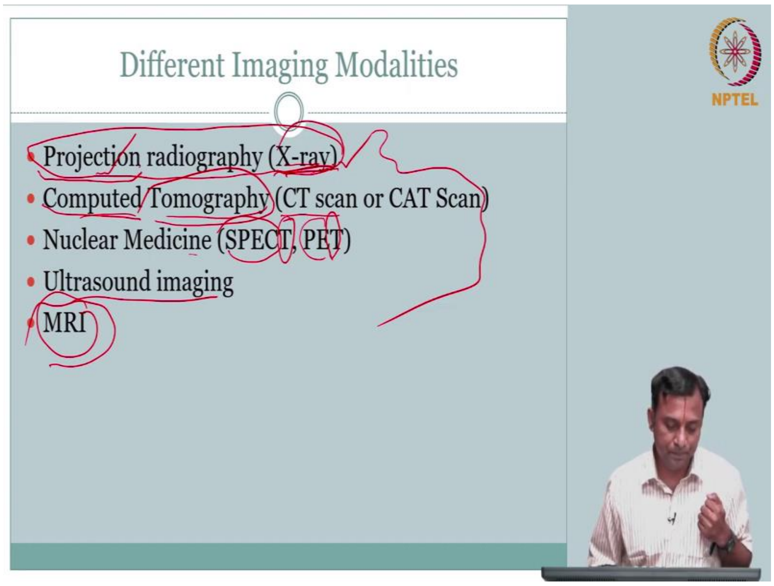
So, I think we are now good to proceed ahead in some sense to the again it is going to be still the Introduction, but then modality-specific kind of a big picture view of each of the modalities; you know historically where you know when was it you know started to being used for medical imaging and how it has progressed and can we identify few big names you know we have contributed a lot to the development of each of the modality so, right.

So, having looked at terminologies right, I think going forward, whenever there is the usage of some of the terminologies that we have covered so far, I will try to highlight reiterate that way you would be able to connect and reconnect with its just a question of getting familiarized I think there is nothing. It is all very I mean the thing that I like about this subject is its very intuitive right at least the most topic is intuitive and you can visualize it.

And so, it kind of you know it was starting to make sense and you will be able to feel for what it is, but then also you have to be cautious that even though it may seem it may give a feel-good factor, it still requires the old style you have to spend hours on the details to really know the nitty-gritties to appreciate it better ok.

So, let us take the positives and say, look I saw these images, now I know you know the images there are several different modalities of interest, here are few that were shown, some for an anatomical image or structural image and some for functional image. So, that is you can start to see the actions that are taking place like in PET for example, right.

(Refer Slide Time: 02:24)



So, let us go forward, let us see what the modalities of interest for this course, this module and kind of delve you know some minutes that it deserves to at least appreciate you know how far each modality has come through and what is it they what is their role in the current state of things and if possible you know you can orient yourself to see where can I push this state of the art right are. So, the different imaging modalities of interest are going to be we saw this X-ray-based projection radiography.

So, now, I think you should be able to quickly recognize what we mean by projection right. So, X-ray ok that is the modality we talked about, which we will again go one by one, one more time, but just to kind of complete make you aware that why we covered certain terminologies before we came here is, if we are going to use projection radiography without telling you what projection means right, it will not you will not get a feel for.

Now, looking at the name projection radiography, immediately you should start to recall you should start to appreciate what modality, what images you have taken so far what you have seen so far that can come under projection radiography right. We have done that we will do it again and again because this is something that you would have experienced personally as was just X-ray right. We gave an example of chest X-ray volume collapsing to a projection.

So, projection radiography and then computed tomography, this is very important because as it says it is just computed tomography. So, it is essentially mathematical right it does not tell which signal it is right.

So, you people call it CT scan, I go for CAT scan, but most of the time they are implying that it is if they say just CT or if they say CT scan they kind of implicitly mean because of the popularity is X-ray based computed tomography signal of interest is X-ray is the probing signal.

And notice here then is nuclear medicine, why did we cover the terminology here? What is this T? This T is tomography. So, tomography is a mathematical concept right. So, it can take the signal the physical meaning of the signals or the variables that are operated in the mathematics can have meaning based on the signal.

So, it can be X-ray-based, it can be nuclear medicine. We will expand all this going forward, we already did this, this is positron emission tomography right. So, you can see why we covered projection. Now, you know why we covered tomography, what we mean by tomography recall right, we take projections, we take views from different views, we take projections from different views and then reconstruct the through slice right through direction or the depth direction ok.

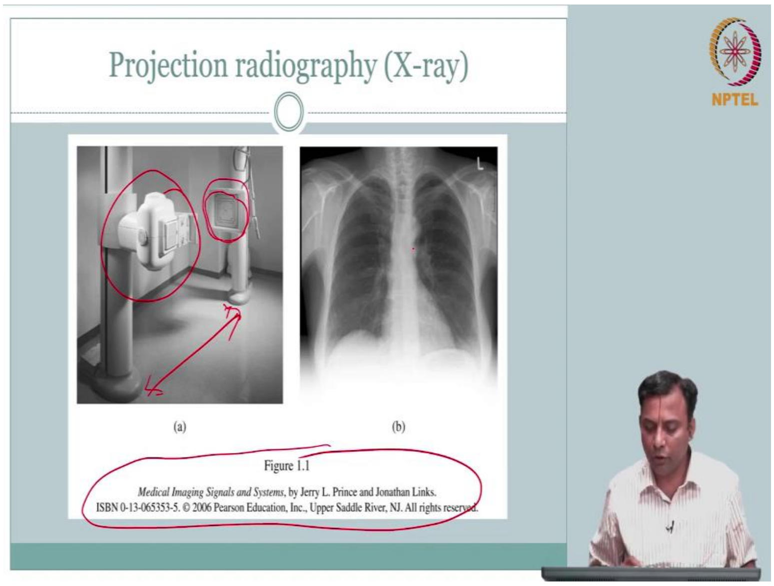
So, then you are talking about ultrasound imaging. So, we will cover about ultrasound imaging. Finally, in fact, the you know it is always the case right, you keep the best for the last. So, MRI it is a very interesting imaging modality very versatile, I think it might be too complicated if we just start with that.

So, we will go systematically in this order. That way, there is some connection between historical development and how the modality evolved and the complexity and the mathematical principles that may that we may use right we can start to sort of add on. So, we get to the most complex and versatile modality towards the end ok, clear.

So, what we will do now is, take one modality at a time in the same order that is listed here and kind of have a big picture view. What do I mean by big picture view? We have already defined objective of medical imagining right. We already defined or discussed the requirements, what is the general requirements for any imaging modality.

So, now and then we also touched base and said each modality is different each one brings different value. So, now, we will try to take each modality listed here and related to whatever we have covered so far with respect to its general how does it satisfy the overall objective, what is it is how does it satisfy the general requirement you know and so on and so forth clear.

(Refer Slide Time: 07:32)



So, let us get to the first modality. I mean like I said this is coming from the textbook reference, but I keep repeating this is something that is very intuitive. You would have worked out at this point of time, most of you at least would have gone for taking a chest X-ray for yourself or you have accompanied someone right.

So, this is what they do. They have a room and there will be a safety signal right; stop red do not enter and then because there is radiation. So, all the information that has to be available to warn you to not just enter to minimize the risk of radiation right will be there. So, you enter the room and you will notice some setup like this and what typically happens is the operator is going to stay go stand there right, he will ask you to stand there and then he will actually politely walk out right.

So, he will not stay in this region and he will go and he will give you some intimation and then say it is done. So, you will not really feel anything. You will just go there you will stand still and he will say ok sir done you can come right.

So, you would have an experience that what is happening? You go stand there this is generating an X-ray it is sending through and you are standing here. So, the X-rays are going through your body coming out through the other side right and it is getting collected here.

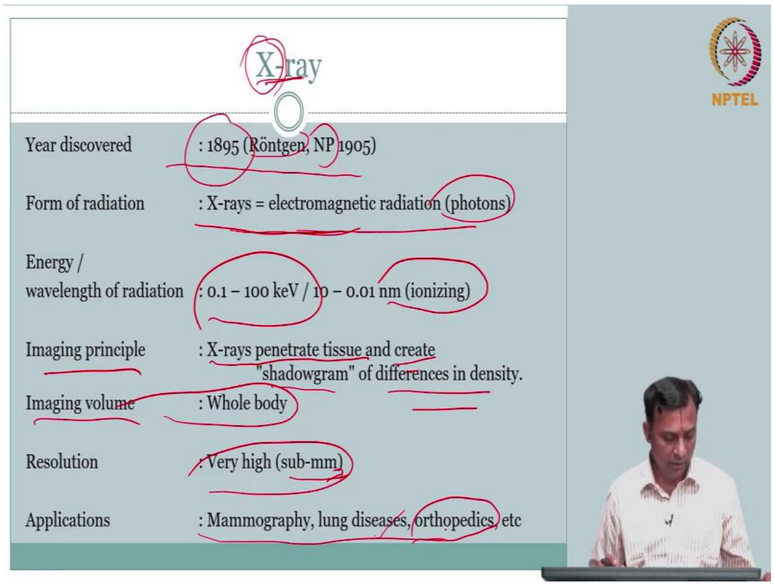
So, in some sense your whole 3D is collapsed into the plane of this guy this detector and then of course, they do the development and you get typical nowadays its digital radiography, but I am sure you would have seen several places a film right they keep it and doctors keep it under the light elimination and see like how you see here.

So, this is something that you are familiar with, just reiterate one more time, the challenge here is it is projection and therefore, my 3D is collapsed to plane of paper. So, I cannot tell from this whether it is a front of my rib cage or back of my rib cage or is there anything if there is any anything that is there right obstructing for example or some nodule is there in the lungs.

I do not know whether it is situated at the mid-level or towards the back or towards the front all I will know is it is there in the lungs at this location, I will not know what depth going from my front to back where that lump will be sitting right. So, that is the challenge. Nevertheless, this is one of I am sure you would have encountered and therefore, you can say that you would not have felt a pinch.

So, it is you know there is no the a person was going to get X-ray projection radiography that is not much inconvenience to them right. So, that is the big plus.

(Refer Slide Time: 10:38)



And also why is it so, popular? I mean chest X-ray is one thing, I am sure you would have gone for regular fracture right. You fall down they would have taken if you fall down and you suspect you broke your arm they will just take a X-ray of your arm or your leg right. So, it is very common. I am sure you would have seen this something number of times, it is one of the oldest medical imaging modality at least the way we defined medical imaging right.

So, it was the X-rays were discovered in the year 1895 by Rontgen. I am sure you would have heard of this name and this no P, NP represents Nobel Prize. So, he received a Nobel Prize for this discovery in 1905. So, you can see it is already more than 115 years old right.

Since if the work was well recognized and I mean there is an interesting story I think I am from what I gather, there is enough concurrence right people agree that the story goes like Rontgen was working on what is called as a Crooke’s tube right. So, it was a precursor to all the other tubes that the X-ray tubes and other things.

So, he was working on Crooke’s tube and he had gone for a vacation and he came back and it was a surprise there right. So, he has he was working. So, he had actually covered well covered concealed the photographic film and he had gone for vacation and he came back and he saw the photography film was exposed and he was not sure what happened because he took all the care precautions, so, that it is not exposed to light, but then he still felt he just saw that it was still exposed.

So, he said ok there is something beyond what we know there is some other rays that is there and therefore, you know if you do not know much you treat that variable as X right. So, he started calling that as a X-ray. So, it was an accidental discovery in that sense it was I mean it will not happen to you or me probably, but you know these are people who are you know not as average as us they are intellectual.

So, somehow it occurred to him that this is not some random error right there should be some science behind it. So, essentially he spent and dugout and he called it X-ray and he did series of studies and then he went on to take the first when immediately it stuck to him if that is the case why do not we you know do it on humans and we could see the insight right. So, that is how its application to medical imaging is started ok.

So, X-rays we saw the electromagnetic spectrum in the previous slides. So, this is X-rays you know its electromagnetic radiation, we call this right it travels the form of radiation is in the form of packets of energy which we call as photons right. So, you send packet of energy. So, X-ray, when they are sending what they mean, is, they are sending energy packets the energy is in the X-ray range right.

So, with this energy, in the electromagnetic spectrum that we saw earlier, you saw that there was frequency axis; there was wavelength, there was energy right. So, you can list this particular you can locate that in that axis. So, this is ionizing ok, what it means to be ionized? We will go I mean.

In fact, that is what we will start with when we start the modality and imaging principle right. What is the imaging principle? So, I shoot a photon right, I shoot X-ray photon that is photons having x energy in the X-ray range. So, it is going through the body. So, when it is going through the body it is going to interact with the medium right.

So, our medium is going to try to stop the photons it is going to take the energy away, so; that means, whatever is coming out is going to be less energy. So, you send number of photons less number of photons will come, how many how less the number depends on which path it is going through.

So, if I have a medium that is going to take more photons right absorb more photons, then I will get less in the background. So, essentially X-rays penetrate tissue and create a shadowgram. So, with light I do this in a typical classroom setting. So, you could perhaps do it.

So, when we have a projector, I keep my hand right and you will see a shadow. So, you can do this you take a light and you show your hands you will see a shadow this is for visible light. Similarly, when you have photons that are going, you get a shadow of how much shadow based on how much is lost when it is passing through.

So, in visible light if I obstruct the light everything is last this is taking up everything is getting bounced back I do not see anything below. So, the shadow will come behind the object in the same concept right, but now it depends on differences in density. So, the density of the material and its properties how it interacts with photons having X-ray energy determines what pattern right what pattern of loss you will see.

So, that is what is the basic principle. So, we will delve on this we will come to it right and then imaging volume. So, other characteristics, what do we mean the imaging volume? Here what is attempted is, you can do the whole body what we saw right now is chest x ray, but there is no reason only for that you can do the whole body or you can do chest or you can do hand. So, this is the upper limit.

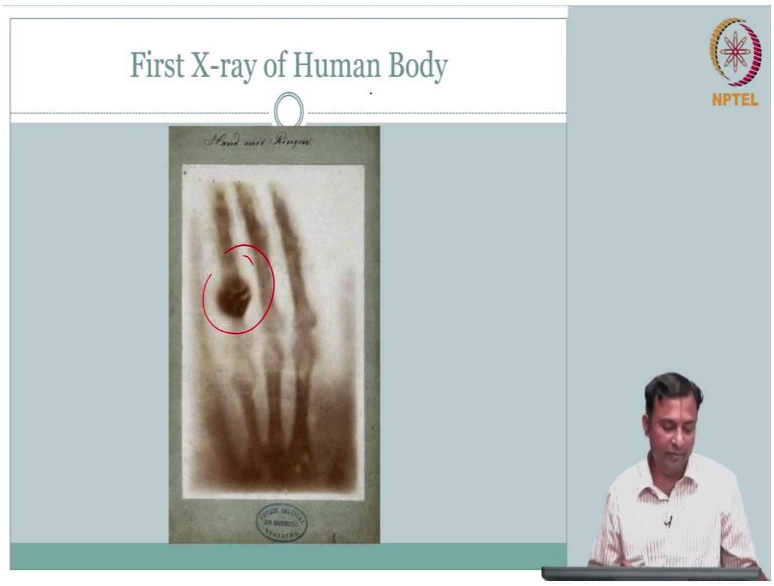
So, whole body can be scanned. So, that is the advantage right. I could quickly have whole body scanned without you knowing anything you without you feeling anything right resolution is also very high what do we mean by very high? This is the context sub millimeter.

So, imagine so, we for example, if I take my height ok, it is I could have tens of centimeters right. So, in case probably 175-76 centimeter, so, centimeters you can get a feel for what it is. So, now, I can see in terms of sub-millimeter from my head to foot.

So, you can start to appreciate. So, if I am 177 centimeters, 1 millimeter is going to you know is already small enough. So, we could actually see details of sub millimeters of how the densities are changing ok. So, you will start to appreciate this. Now, you just want to I want you to have a feel for the numbers right some range at least the orders of magnitude. Popular applications, mammography right, and mammography essentially used for breast cancer screening right are part of the first screening protocol.

So, mammography lung disease right chest X-ray right if you do that they do it orthopedics basically fractures right, so, very common everyday application that you would have encounter ok.

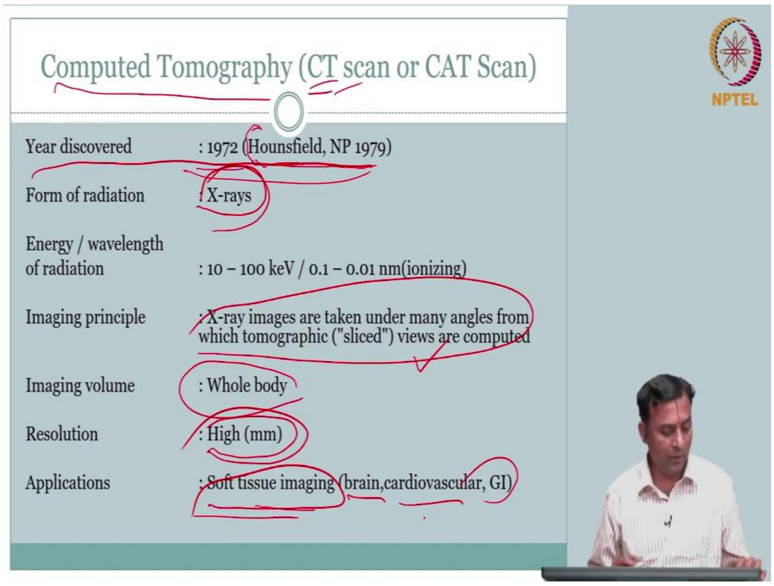
(Refer Slide Time: 18:25)



So, let us before moving to the next modality, just want to throw this and several of you probably would have it is a trivia kind of question you would have you know you would have heard about this in quiz contests or something, but nevertheless it is fun just what is this? This is by the by what it is considered to be the first medical image.

So, we just talked about Rontgen who accidentally discovered X-ray and immediately he was smart enough to recognize its application in medical. So, what did he do? He asked his wife right. So, she showed her hand and this is their wedding ring and so, this you know happens to be the first medical image right first X-ray of human body his hand ok good.

(Refer Slide Time: 19:19)



So, next you probably read it already Computed Tomography or CT scan or CAT scan right. You notice X-ray right, I said it was discovered in 1895 when was CT in fact, when they say year of discovered here 1972, this is essentially you know based. So, this work based on this work where the concept of X-ray projection and the mathematics of reconstruction computed tomography was put to use and you know for which Hounsfield received a Nobel Prize in 1979 ok.

So, again the modality or the form of radiation is X-ray which was there from before, but what was the challenge when Rontgen did it? It was only a projection radiography right you could not see the slice through what happens what is there in the front what is there in the back you do not know everything is projected. You know it took cool 75-80 years to take that physics right how it interacts, how much is attenuated, and the medium property.

This is a nice theory, but it took cool 70-75 years before they were able to put all the pieces together and say ok here is a practical way I could get the slice image of the through slice of the tomograph right. Otherwise, nothing else is going to change because it is still you going to use you are going to send X-ray right the photons X-ray photons right and receive it, but in tomography recall what did we say?

You are going to take projections from different views and then put the reconstruction algorithm right. So, that is what, so, its X-ray projection we saw. So, if you can take the projection from at least conceptually we will see the practical difficulties, but conceptually you take different views.

So, you get projections that are going to look different from different views. We did this right. We took my cell phone and we said if you look at it from different direction, you are going to see different projections, the length was changing. So, similarly this is going to happen and how do you and then you put them reconstruct?

You get X-ray computer tomography. So, the X-ray interaction principle is the same as attenuation with the material property is same as your X-ray projection radiography, but here the extra step is the tomography part. So, same advantage you could do a whole body. So, this is kind of 3D now right.

When X-ray projection of whole body is you are going to get one direction of me. You can either collapse me from the front back or you can collapse me from sagittal right; coronal, sagittal or axial right it does not matter. Whereas, here you are going to get 3D right you are going to get slice. So, you can actually see every little detail where it is situated in x, y and z ok.

Resolution; yeah you have to go you know there is always a compromise you will see that is the whole idea. There is always a compromise when you gain something there is surely something that you are going to lose. If that is not the case then there is probably something wrong you know unless it is a paradigm shift it is completely new.

But anytime you are working with existing well accounted, well studied you know modality. The challenge is always it is going to be there is no one way street right. So, here what it is? Resolution is still good, but not sub-millimeter, it is millimeter right. I cannot get too greedy right. I am now going to get x comma y comma z of my material property, how it attenuates X-ray and if I can get that at millimeter resolution right for every millimeter comma millimeter that is probably good.

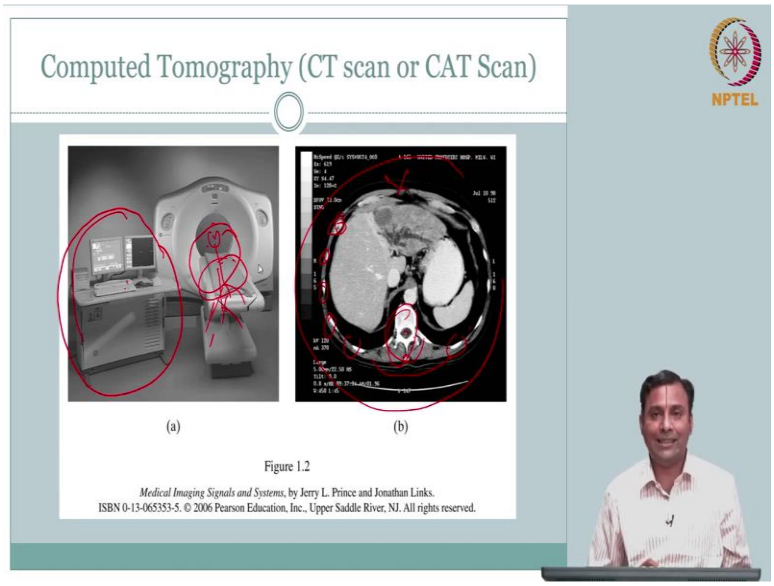
You know of course, if it is sub-millimeter you would still like, but then it is going to take you know you are going to trade off somewhere. So, we will look at it. Again application you see soft so the moment you said we know X-ray based imaging projection radiography was used.

So, if wherever there is a projection radiography can solve the problem right you do not really need a CT. I mean if I can tell there is a bone fracture here, a quicken you know safe X-ray projection radiography that is good enough right, where CT contributes is it provides good soft tissue imaging.

So, if I want to not just look at whether there is a bone fracture or a skull fracture, but I actually want to see you know the different soft tissues. I want to differentiate one soft tissue from the other soft tissue, then this becomes very important modality ok. So, brain we actually saw some example, cardiovascular you know CT angiography right you would have heard about that and then GI. GI is your Gastro Intestinal.

So, you can do lot of CT in fact, the example image that I have is also going to be from cut section through abdomen.

(Refer Slide Time: 24:55)



So, what is addition? The instrumentation is now getting little complicated in projection. In X-ray projection radiography, you had source and you are asked to stand at the detector you know your back resting against the detector or front rest does not matter. And then procedure is done you will just come out whereas, here you notice the patient has to lie down right he has to lie down here. Apart from that what is this?

It is computed tomography. So, I need to acquire the data from different views. So, I need to have the ability to send X-rays through different directions in the body, collect them, and then put them into the computer and do all the reconstruction. So, both are intertwined. So, you have to have both before you can see the image how does the image look? Here is an example right.

So, what do I mean you know it might look yeah there is some image, what do I make out of it right. So, I am not a clinical practicing radiologist.

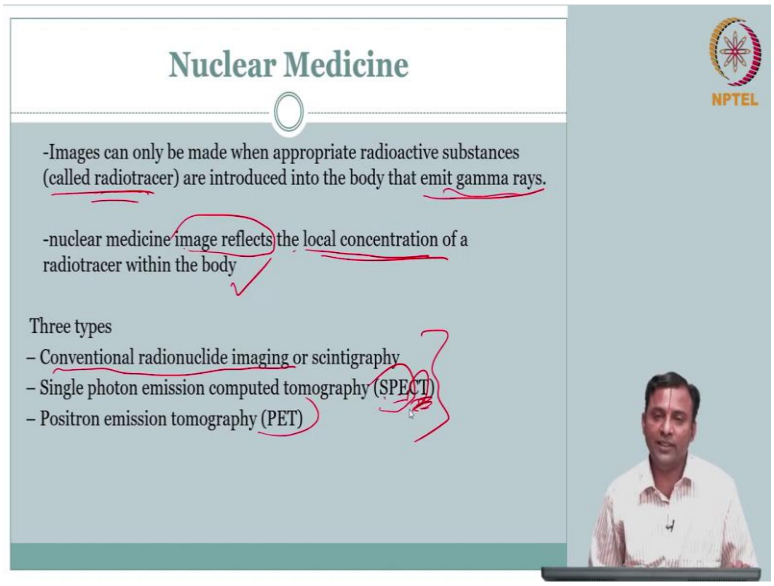
So, I am not well equipped or trained to say the detail of what each organ is and whether they are normal or abnormal, but what I can tell you is mathematically what is happening is, this is your spinal cord right this is your back. So, this is your lying down. So, this is the back part this is your spinal cord and this is your front of the body right front that is your back.

So, clearly, if you start to imagine if I am lying here, and this is my front back. So, essentially this is a axial slice that is cutting through right remember axial. So, now I see ok axial slice. So, this could be ribs right these are ribs. So, imagine this is why I said do dummy experiments in your home right, just look at objects and visualize their projections that will be very handy.

So, here if you recollect, if I see through right if a X-ray goes through like person is lying down you are going from front of the body to back of the body this is tomo. So, you are seeing through the slice, it does not collapse. You see through the slice I will see you know a rib cage cross-section of the rib cage yeah it will be like this, a cross-section of my spinal cord right if I cut through my spinal cord will is say cylinder. So, if I cut through it is going to be whatever. So, yeah it makes sense right.

So, this is the advantage of CT you can actually start to appreciate different organ. So, soft tissue contrast can be obtained ok and this you can do in whichever direction example here is axial good.

(Refer Slide Time: 28:06)



So, next to nuclear medicine right, so, in nuclear medicine, what does it mean by nuclear medicine? So, here see until now what we progressed is X-ray is used as the modality or is the energy that is used, but notice both X-ray projection and computer tomography we were talking about X-ray being generated outside, it is sent through the body it interacts with the body and exits the body.

And you are capturing the X-rays the photons with X-ray energy that are exiting the body right and you are inferring you are saying the amount of loss of that photon is related to the property of the tissue right and that is what you start to see. Whereas, here what they do is the signal right here we are talking about radioactivity.

So, essentially they ingest. So, they give you radioactivity, it is in small quantity that is why it is called as radiotracers. What happens when you have radioactivity? We will go into the details, but you know from your high school physics that you know there is a it will break down into more stable isotopes right.

So, you have radioactivity. So, it will start and in the process it will send out energy. So, it will emit gamma rays. So, its again electromagnetic radiation, but with a higher energy.

So, they will have you take some radio traces right injected or you know oral we can drink some solution. So, it will go into the body then what happens? That radiotracer is going to take part it is going to circulate in your body and wherever it goes and wherever it takes part in some activity, the radioactive decay it will start happening.

So, essentially you are sending the signal source inside your body, you have a detector that is surrounding and you catch the signal that is coming out or the radioactivity that is coming out. So, if you can catch that and say I get the radioactivity, you do the tomography right.

So, you do the calculation and you say I got so, much activity and it came from this particular location right. So, your image is going to tell me which location is going to be how active ok. So, in this, the slight difference is that it is still noninvasive ok because, but you notice that is a kind of sleight of hand we say its noninvasive, but your source is going into the body ok.

So, that is the idea of introducing a radiotracer. So, you emit some photons again electromagnetic radiation with a different energy higher energy and so, it essentially you can local concentrations within the body you can start to tell ok. So, nuclear medicine image reflex. So, what do you see in the image? It has to do with a local concentration of the radiotracer, some location there uptake of the radiotracer might be high or washout might be there.

So, that is what you are doing. So, there are three different ways which is again in some sense, straightforward if we understand if we can do the same thing with X-ray right. If you this is just the high energy only thing is in X-ray I sent from outside I get it from the other side and I say in chest X-ray projection radiography right. I will use the depth information right.

So, but I can say along which position x comma y if z is the depth right you do not know which where it is situated along front-back, but otherwise you know. Similarly, same logic what why if the source is inside the body how does it matter? If the source is inside and emitting radioactivity, the radioactivity will come out of the body whichever direction right.

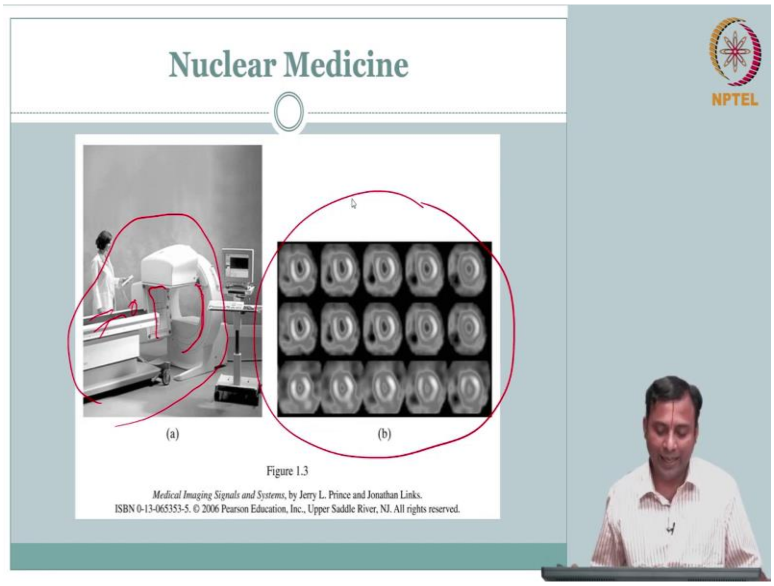
So, if I have a detector here and the radioactivity is coming out and hitting the detector and I collect then that alone is sufficient for me to tell it came from this location I do not know whether it came from front of the body or back of the body. So, you could straight extension of logic of what was done for X-ray projection radiography you can get what is called as conventional radionuclide imaging or scintigraphy.

So, you take the source right source is going to give the signal out, I just collect the signals and I say the signal came from this line of say I do not know from how far behind it came, but it came out exited from here it exited from here it exited from here. So, you get a distribution on the projection plane or right that is straight and then if you do X-ray computed tomography you could use the same mathematics right you could get tomography.

So, I could get single photon emission computed tomography or positron emission tomography. So, we will go into the physics. So, we will talk about all the details, but the idea of what is tomography and what is the view and how we get this image. Now, probably you start to see what is the at least there are the aspects that are changing and that is not changing trivially.

So, here we are talking about radio traces being the signal source mathematics and the logic of forming an image and visualizing it is similar.

(Refer Slide Time: 34:01)



So, here again just to show the setup you know this is your patient will lie here go in and you have some mechanism right, it will move around your body you have to get views right you have to get views different views and so, so as to do the tomographic reconstruction. So, that is what this arm will do right you see this l right this is going to move right it is going to move around the patient. So, you can get different views we will talk about the details why is it placed like that we will talk in detail later.

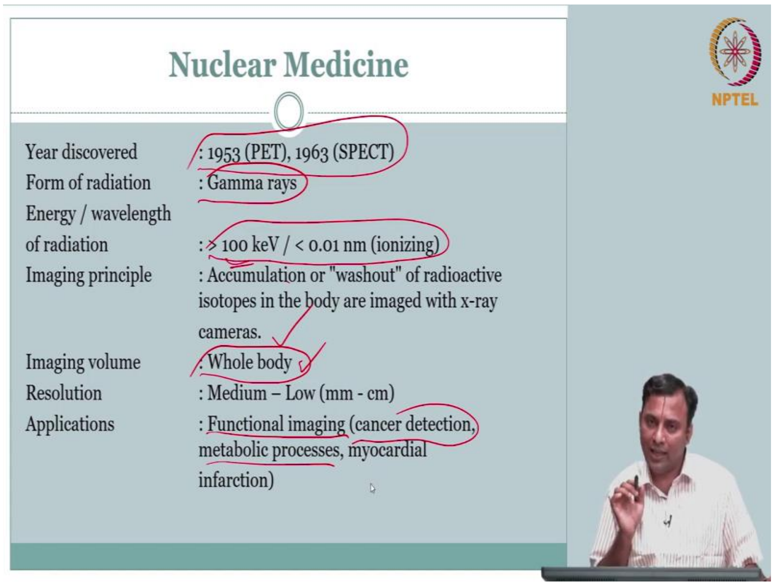
Apart from what is not seen, of course, you have to have a computer, all those things are fine, what is another important aspect for this? You have to prepare the patient right it is not like X-ray projection radiography for example, you just walk in you go stand there and you get the he says job done you may please leave. Whereas, here they have to prepare you, what do mean by prepare? They have to send the radiotracer into your body.

So, they have to choose some route either make you drink and wait for some time. So, that the radioactivity goes to the desired part where it is going to say for example, if you want to see your metabol, your problems in your stomach right you want to see your you know digestive system you want to see how it functions.

So, they will ask you to drink some radio tracer that can become active depending on the activity in the stomach right. So, metabolic activity, so, it will go they will ask you to drink and wait for some time and then by the time, it would have probably gone to different parts of the body and only the locations where there is activity it will tag on give the signal out.

So, patient preparation is a key here ok otherwise you are going to get of course, this is not color image, but you may want to recall the brain scan of PET that is typically shown that is how you get. So, it will be a color coded image the color correlating with some functional activity.

(Refer Slide Time: 36:14)



So, just to you know relate to again this again dates back to from the PET point of view right as a system dates back to you know 1950s. So, here we are using radiation is gamma radiation. Again in the chart that we saw the electromagnetic spectrum you can locate this will be high energy ok.

And I think imaging principle we saw. So, especially you give the radio tracer, it is going to accumulate wherever there is activity and its going to send out radio activity from that location and so, you infer from that activities the concentration of this radio tracer is related to the functional aspect of that physiology.

Again the advantage is whole body. So, essentially when you take the radio tracer your circulatory system make sure that it goes into you know it circulates. So, potentially you can send out the radio activity from any part of the body, but depending on what that radio tracer is right.

If you are doing kidney maybe it will be tagged with urea. So, it may go lot more activity will take place in the kidney and the bladder. So, if it is going to be iodine for example, it may be going to your thyroid location. So, they have I mean we will get into the details, but the idea is you are now walking source right or you are emitting your radioactive source your walking and in principle it is if you can do the whole body scan right you might know where all the activity is happening.

So, this is very powerful advantageous in especially cancer imaging right. So, you do not know where in which part of the body maybe there is cancerous growth right. So, typically cancerous growth means it is going to it is going to be high more active than the metabolically more active than the remaining.

So, its it has a accelerated growth right. So, in that sense it may be deep inside the body it is not going to be a lump that you sense that is fine that might be the lump, but you do not know where all it can be. So, whole body imaging of PET is very useful in getting you know sense of that.

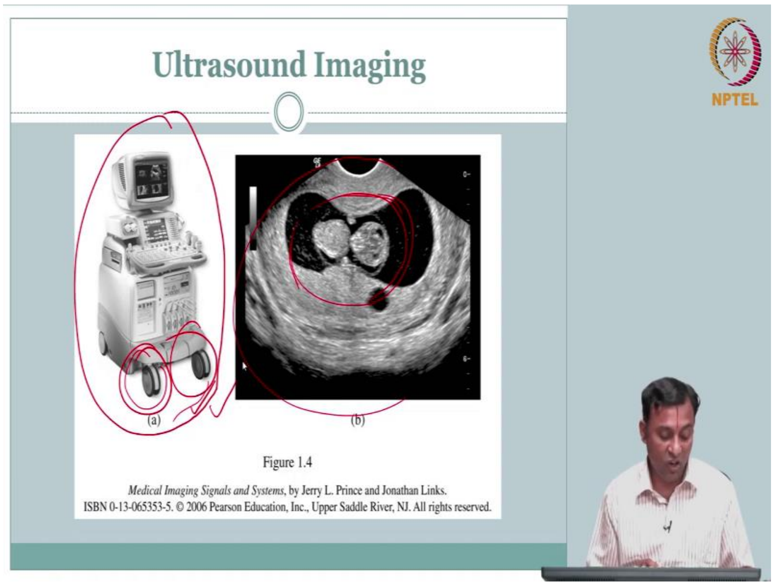
So, the lot of applications mostly for functional imaging applications wherever you want to see say metabolic process myocardial heart attack right myocardial infarction or cancer detection. So, any of this it is used. You know I mean all of this you get a sense that from whatever we have seen so far there is some risk right.

We talked about ionizing we did not go into the details, but we already see, but look at how complementary the information that you are trying to get and that is the reason that each one has its new information that it is contributing.

So, it is always a case of risk versus benefit evaluation right and you always favour I mean ideally you want zero risk and maximum benefit. So, there are applications where you know that this is probably the way to go even though you know the risk is, there is more risk associated with it, but you may not have a choice right.

So, it is important we understand this overview big picture view and then the limitation of each of the modality so, that we are always in the back of their mind right, our engineering brain is kind of always looking for some solutions ok. So, that is what I want you to appreciate.

(Refer Slide Time: 40:11)



Then we move on to non ionizing. So, now, we will just look through couple of what is considered to be a very safe imaging modality one is ultrasound imaging. I am sure actually I will take by I am not that sure it depends on which generation is going to the clinic. So, if these are very standard ultrasound images, you would have seen if you had gone right in the 2000s or you know until a decade ago or even a little earlier.

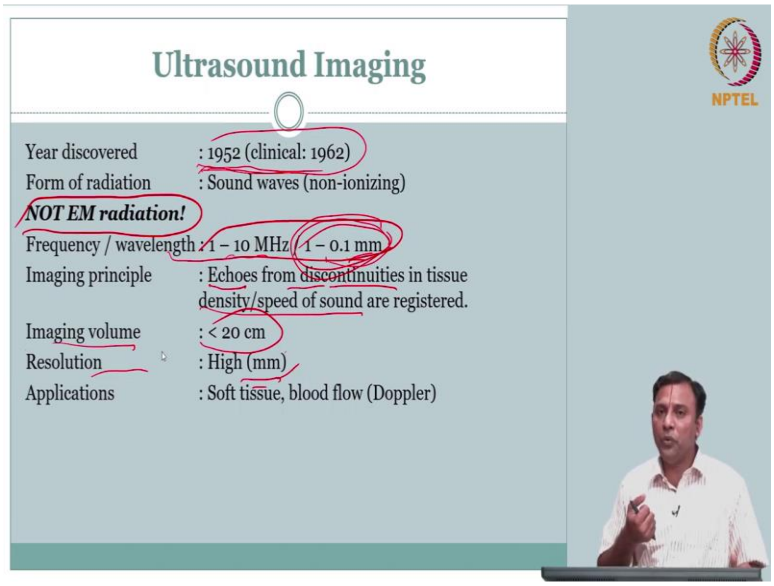
But nowadays you know you even get ultrasound scanners what you probably would have seen. There are pocket scanners, mobile like laptop-sized scanners, and so on and so forth, but this is a very typical ultrasound imaging machine. Even at this size right when I say compared to a pocket or a mobile this is still big.

But even here, you readily appreciate that this is on wheels, unlike your CT, PET right. So, this is already compact and has wheels, so you can take it to patient side right, you can move around. Also, you do not have to have a dedicated room where, they have to prepare the patient and send in you know. So, those are the advantages and this is how a typical image from an ultrasound looks like.

If you I mean the most common image that most people would have seen is you know fetal imaging, so that kind of tells you. So, every other modality has some limitation right with safety especially whereas, ultrasound is a stable right is there is no known biological affect both on the mother or when the baby is developing.

So, it is a vital tool for the doctors to assess the baby's growth inside the tummy. So, very powerful imaging modality and very interesting imaging modality compared to the others, interesting in the aspect that I highlighted already. All other modalities are coming from the electromagnetic spectrum right this is not ok.

(Refer Slide Time: 42:28)



So, here again these are some things that are commonly available dates that I have put here, but the history of each of this modality is itself very interesting. So, I understand that lot of work went through after World War I you know the Titanic that sank. So, they wanted to basically look at where these icebergs are right in the Atlantic Ocean northern thing because they wanted to prevent or they had to have some warning system.

So, lot of work was done using sound for underwater obstacle detection right. So, you would have heard a sonar right. So, lot of activities started taking place in the 1914-15 in that context, but early 50s its started really coming down as the imaging modality and in some of the historical pieces that I read it says you know it is again it is a side effect or a positive side effect of the World War II where there are lot of sonar submarine detection systems right.

So, they have a lot of engineers who were trained with sonar to detect submarines, the enemy ship that is under the water right and then they came out the war is done now its peace time there are lot of technology that was built, how do you use it right? Brilliant minds they had the engineering know how they had a target then they realized underwater human body is 70 percent water why cannot we use the same sound in the body right?

So, you know you have so many smart people who are other ways very qualified got to do something the war is over. So, they just sat and very innovative minds put together and they got some application for clinical as well and therefore, I mean so, that is what they say clinical application year of, but the idea of sound and other things was lot earlier than this ok.

Key no electromagnetic radiation ok. So, that is the real key message or uniqueness of ultrasound imaging compared to the others so, far what we have discussed. Look at the range right. So, now, we are talking about pressure wave frequency not the electromagnetic wave frequencies right this is pressure wave frequency. Pressure wave is a 1 to 10,000 10 mega Hertz cycles per second right or you get wavelengths in the order of millimeter fraction of a millimeter ok.

So, in some sense as you will see when we go into the physics and the mathematics you will realize this lambda is a key that kind of tells you see you already see the units it is in length scale. So; that means, we already talked about resolution right we already talked about resolution that is also in the length scale. So, we will realize that the lambda has a very important interpretation or usefulness in telling us the resolvingability of the modality ok.

So, this is good that it is in the fractions of millimeters, what is the imaging principle? I mean, I just kind of touched upon with mountain example for echo, but here most commonly used ultrasound scanners use for imaging use what is called as pulse echo; that means, you send the pulse of sound wave and the echo start to come back as soon as it encounters obstacles right.

So, echoes from discontinuities in tissue. So, I am talking here we will talk about details later, but just for example, when I am talking I am in a room right when I am talking it is going in one direction, but the moment there is an obstacle there is a wall there is some obstruction my sound wave right the pressure wave gets hit and it will gets reflected or it goes to other part of the room right or we are interested in the part that is coming back that is the echo ok.

So, echoes from discontinuities in tissue. So, when you send it through the tissue there is lot of interfaces obstacles. Path is not straight it is not just water from top that is from outside your body to inside it is not just pure water. There are soft tissues right each one is slightly different from one another and therefore, these are kind of obstruction to the path of the sound that you are releasing into the body.

So, it will get echoes and you are going to get echoes in several directions, ok. So, that is, but the idea is you catch hold of these echoes and say this echo came from that location. So, that location property how it how much it reflects the acoustic pressure is a property of the material how it is distributed is what you are seeing ok.

So, we will go into the details of that, but just for your appreciation. So, what we call acoustic properties of the material is what we are going to go after. Again this is stating as emerging volume just to be consistent with the previous modalities, but what we really mean here is the disadvantage of ultrasound is you cannot do whole body like what we saw for CT or X-ray projection.

So, here you would have noticed even the slides that I showed every time a scanner is there is a operator who has a scanner in the what we call as transducer in hand and they probe your body. So, essentially your field of view is very limited. You can go to a location you want and from skin inside the body you can go in the order of centimeter that is a plus compared to, for example, optical right.

Optical comes out from the skin you cannot really see inside. Here you can go for several centimeters. So, 20 centimeters is no joke I mean you can you know you can really see. So, 20 meter 20 centimeters from if I keep it from the front, I can go back and do 20 centimeter.

So, I can 40 centimeter second too. So, it is fantastic. So, it has and that is. So, you can still push it further with certain compromises. So, essentially it is not volume it is a image. Ultra sound volume images are coming to the markets, but still staple is your imager right.

They move the transducer you have real time feedback. So, the doctors trained doctors radiologists reconstruct the 3D in their mind right you do not have mathematics tool re project and do all the 3D stitching algorithms they just their mind stitches the 2D, they move. They visually map how the 3D is going to be from the 2D right.

So, it is a very trained specialty it is dependent on the operator unlike your CT or NM X-ray projection radiography that we have seen so, far, but the good news it is applicable both for soft tissue contrast it is not so, good in extremes say you do not really see it as a staple application for a bone fracture right.

But it is very good with soft tissue contrast and blood flow using Principle of Doppler ok. So, we will get to that. So, these are so, you can see blood flow and soft tissue blood vessel and the organ that is holding the blood vessel. So, it gives a wholesome picture, but it is very limited from the field of few points of view, ok.

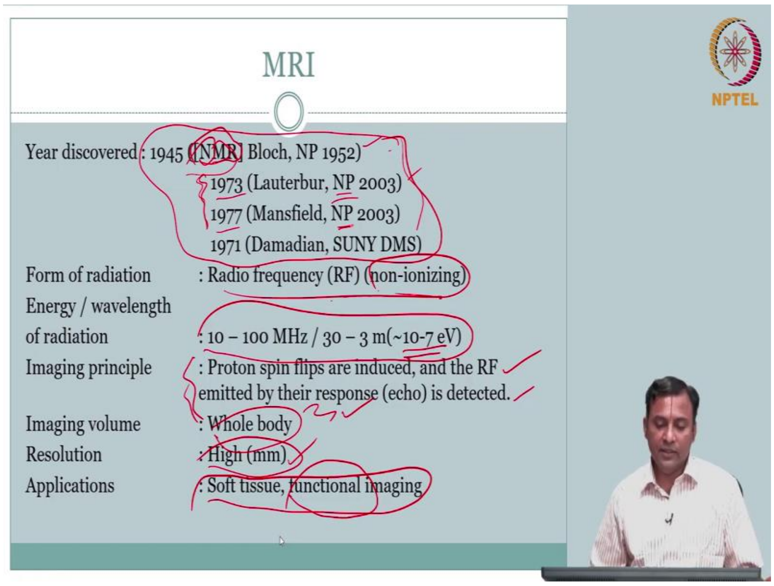
So, I have really held myself up so, far going one modality at a time and I said I promise that we will get to the interesting one in the end right.

(Refer Slide Time: 50:42)

Magnetic resonance imaging so, this again is a fantastic modality. What is not really captured in this image that you see is it just shows a typical MRI scanner. What is not captured is this requires lot of infrastructure. So, this has to be in a room and then you know a whole set of electronics goes around this and there is a separate room where an dedicated operator technician has to be there and the patient also has to be prepared before they come in right.

So, if they have for example, if they have some implants or anything they may or may not be suitable, you cannot bring your wallet in right key chain. So, there are lot of infrastructural requirement and a technical support that is needed to do the imaging that is not captured here, but from a technical perspective this is one of the versatile imaging modality.

(Refer Slide Time: 51:55)



So, what do we mean by that? You can kind of start to appreciate why I said that from probably a very limited list that you see here right. A quick Wikipedia will tell you that for MRI it was this N is Nuclear Magnetic Resonance right. So, you have any material you go you have an atom you have a nucleus right. So, nuclear magnetic resonance how does the nucleus right? What is the magnetic resonance property of that? That is what they were exploring.

So, that was part of you know. So, several different Nobel laureate’s different eras. In fact, Nobel laureates they got you know from chemistry they got Nobel Prize for NMR physics they got and then what is listed here. These are discoveries done in 70s right discoveries more like you had all the nuclear part's physics and chemistry. Of course, after World War II you know nuclear become a very difficult term to handle right because of nuclear bomb and all the things.

So, it took some time, but then they realized that property can also be used for our advantage. So, the magnetic resonance property of the nucleus can be exploited right and that kind of opened up a lot of things which we eventually started calling as MRI, Magnetic Resonance Imaging a pioneering work was done by Lauterbur and Mansfield right.

So, essentially here again there was physics and chemistry from before it is a smart I mean complete understanding of that and a smart way of coming up with the instrumentation and reconstruction strategy right to exploit that and come up with the image ok.

So, they got a Nobel Prize in the early 2000s for that of course, there are was also a work from Damadian which was contemporary who had also done lot of work in demonstrating that you could exploit the nuclear magnetic resonance principle to come up with you know imaging right medical imaging purposes.

So, you can already see you know very recent in the sense that you see the Nobel Laureates is you know only couple of decades ago and from an instrumentation point of view from use of MRI for humans is actually real serious activities is last 2-3 decades. It is one of the newer modalities amongst the most popular imaging modalities on market right.

But you can see already how interdisciplinary it is there is you know, I mean you have physics, chemistry, mathematics and then people who put the instrumentation together. So, by no means you should consider that I did an MRI was considered or treated handled in the introduction to medical imaging.

So, I know MRI. Please do not falsely convince yourself. The attempt here would be maybe after this, you will be able to appreciate the modality you will be appreciate the different aspects that maybe you want to go brush up before you can jump in and start to push this to the next level that is the you know humble hope in these modules that I will cover for MRI.

But again radio frequency, where is this radio frequency coming? There is magnetic part and then you are going to have other set of electronics you are going to make it spin right the spin property. So, it is going there are many frequencies involved to make the nuclear spins and that happens to be in the radio frequency.

So, it is not ionizing that is the key ok. So, it is also a safe modality in that sense. So, you can see here right its already low energy. So, it is nothing. So, from a safety point of view, there are no known worries about MRI, but again, this is the very simplistic principle listed here. Just to be consistent with the other slides it is put in two lines, but it is not anywhere. The emerging principle for MRI is little complicated to explain right, it has its own due diligence that needs to be done.

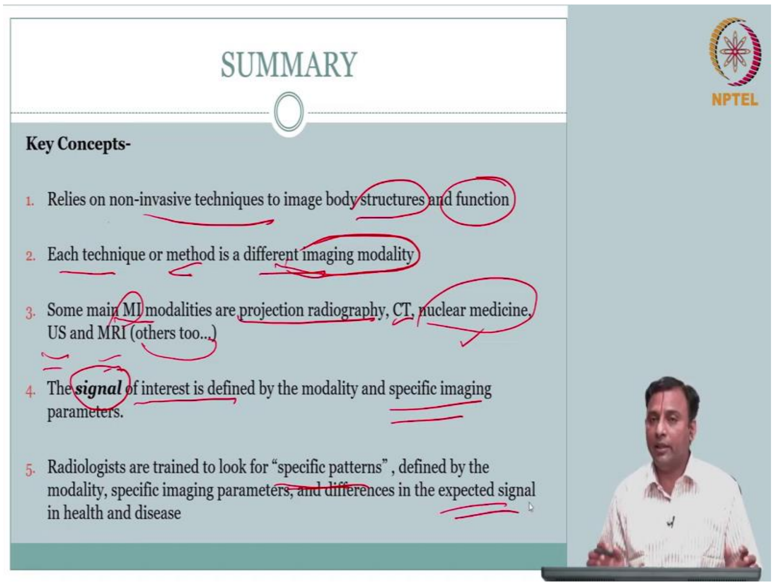
Let us say for the moment there is a atom. So, we all are made of material there is atom and you know. So, there are lot of hydrogen atoms in our body and so, hydrogen atoms are having its own spin characteristic and so, essentially what we are interested is in understanding how where all hydrogen is right hydrogen density, proton density and how do I exploit the spin property to say how much protons are there in which location ok.

So, this is not like straight like your tomography because we are going to get volumes and through scales what you have seen, but it is not really like in that sensor tomography not done in the same big picture like your tomography it is like, but its little more complicated than that.

For now, I think it is better we just say ok there is you know hydrogen atom, there is nucleus, there is a spin property and that is what is exploited high resolution whole body these are the big plus. So, you put them into the MRI scanner, you can do a whole body scan.

Resolution is reasonable right; its high right millimeter is is good enough. So, again versatile I say because it does both soft tissue and functional imaging. So, you can get structural and functional imaging, structural of soft hard everything. So, it is powerful ok.

(Refer Slide Time: 58:07)



So, just to summarize the introduction, so, what have we done so far? Some of the key concepts that we covered before we close this introduction and move on to the next topic, first we talked about non-invasiveness that is the key right. So, all medical imaging modalities rely on non invasive techniques to image the body both structures and functions that are the key concept. Then, each modality is different right each technique or the method is different we different.

We call it a different imaging modality ok. So, when they say CT or an MRI, each technique is different, different method right based on different imaging modalities.

So, we covered some imaging modalities this MI is for medical imaging some main medical imaging modalities that we have so far at least spend some time a slide or two few minutes. Projection radiography, CT, nuclear medicine, but nuclear medicine is again a vertical that uses these radio traces and gamma, but within that we started spelling out few specifics right PET, SPECT right.

So, that is under nuclear medicine. Of course, we talked about towards the end ultra sound and MRI. There are several I mean if you recall your optical imaging right photography is its some is also a medical imaging. So, whole optical imaging beyond your just photography is a rich field that is active.

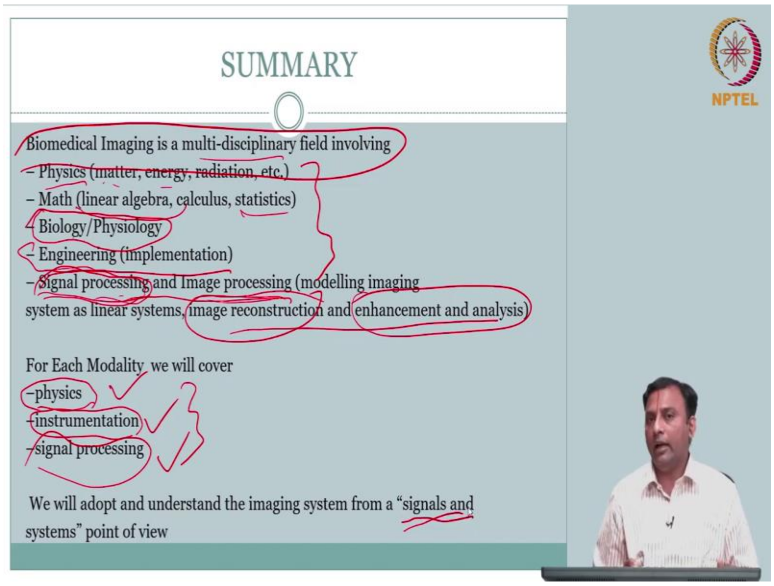
So, we are not covering. So, there are then there are multi modality right you have combination of different modality. So, we have not really covered any of that ok, but these are the common ones that you will encounter and provide a good starting point.

So, the signal of interest is defined by the specific imaging parameters. So, this is the key ok. So, what we will end up doing is, we will now when we get to we will take each of the modality as a separate module, we start with the physics right and then go through the process, but we will take this view of signal right.

So, what doctors do is, they have this image the overall objective that we said doctors essentially take this image, they look for specific patterns right. If there is something abnormal pattern they say there is a new growth here that might be a tumor is it cancer benign that also you can use the modality to do or you can take it out and do the conventional way, but the idea is the doctors look for this pattern.

So, they get these images look for certain patterns whether it is normal or abnormal for that given structure or physiology and then they make up based on this expected signal they make up way health of health or disease of the thing. So, what we need to do is, we need to take a holistic picture of each of the modality.

(Refer Slide Time: 61:41)



So; that means, we are not this is not a clinical viewpoint that is why I said that. So, the doctors will do that, but here our perspective is not that it is not clinical diagnosis. For us we need to look at it from a multidisciplinary field right because it is going to have physics, chemistry, electrical engineering, mechanical engineering, whichever way you want to look at it.

I mean I for me you know it is all engineering, but you can certainly look at it if you are from certain vertical electrical engineer or mechanical engineer you will see that you need to understand the other aspects to some extent still before you can make a contribution to the system.

So, at least my view is all this will be encountered ok. So, you will have to have some you know physics you have to understand some physics; matter, energy, radiation. We already talked about radiation all these key words we had in the bullet points, mathematical reconstruction you are going to do.

So, you are going to be linear algebra, you are going to have statistics right, maybe we will go little low on biology and physiology little low. The reason I say little low is that our object is not to do interpretations of it, but we still need to know how the signal that we are measuring is related to biology or physiology. So, that level we should be able to at least position our understanding of the imaging concept with what is there.

Key engineering what I mean by that is implementation, you acquire this image you register, but then somebody has to implement either program the scanner to take multiple views, take the data, process them, form an image all of that requires engineering implementation either hardware or software mostly it is interlinked ok.

And then signal processing and image processing. Again like I said we will go little low on image processing. We will work on signal processing again not from typical signal processing course that you would have been exposed in electrical engineering for example, that is not the signal processing we are talking about.

Some signal processing will be in the context of you know how do you recover reconstruct the data. So, it can be seen as applied mathematics ok. So, data handling,, but at least signal processing we will cover when you get the raw data to how it transform to an image.

We will have some signal processing concept, but image processing we will avoid ok because that is not the course intent. All the other things right this we will not worry too much reconstruction we will, enhancement analysis this is not something that we will worry about, but you can see why it is interdisciplinary all of this makes a good system.

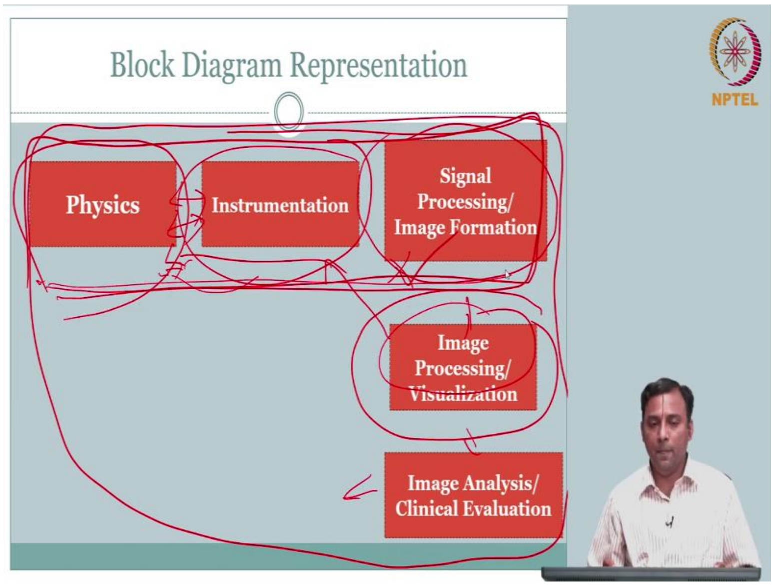
So, with this background, we will cover each modality we will take each in the same order that we covered so far right. We will talk about the physics first and then try to relate that if I have to use this physics apply this physics right I need some instrumentation to do that.

So, we will talk about the instrumentation and then instrumentation gives access to some measurements. You need to talk about signal processing because your objective is not just the measurements you want to see an image of that parameter right. So, there is going to be signal processing aspect to it.

So, for each modality we will go in these steps. So, in some sense that is why I said we will I kind of like the textbook that I underlined in the reference right, where it is covered from a signals and systems point of view. I think this is a there are several classic books that I listed in reference from the imaging physics point of view.

But to a reasonable extent the textbook that was highlighted takes a signals and systems point of view, I found the content to really jell well for a typical biomedical engineering or a engineering student who is trying to get into biomedical imaging right. So, there is some concepts organization that involves both physics instrumentation and signal processing. So, we will adapt this point of view clear.

(Refer Slide Time: 66:34)



So, last, but not the least just to give a you know block diagram view of the same texts that we had. So, this is somehow the way I have it organized in my you know my perception. So, I look at when we talk about imaging systems everything is interlinked. You have to understand the physics, understand the instrumentation right within the context of the physics, and then understand signal processing.

When I say understand you might think yeah I know signal processing. I mean I am electrical engineer major and I did signal processing elective as well and so, I am very good at signal processing. But then when you look at the full imaging system right or this area of medical imaging, it is still important that you are very comfortable with this part you still need to know these two.

Likewise most common job people get right they get image processing, but image processing of a scene photography and image processing of medical image you can use the same mathematics right same filtering you can start I mean that is important that you understand basic image processing.

But in order to effectively apply two medical images you need to understand the instrumentation and physics because this gives rise to your raw data. If your signal that is coming the image signal that is coming is already of good quality right then image processing is going to work right, it is always better the input. Your image processing will probably make it better or it will it should not make it worse right then you are not going to do additional processing.

So, it is very important that we are paying attention to these three in this course. A follow up course could be medical images processing, medical image visualization, medical image analysis all of these could be a top up course specialist course where you know the physics of the image that you are going to play with process right.

I think that is the intent of this course. So, we will focus on these three blocks. In fact, we will cover each of the modality in this order physics, instrumentation, signal processing, image formation. Of course, conclude with some insights on application, but majorly emphasis will be only on these three ok.

I think with that this is good to go let us stop here. We will then proceed ahead with the next topic which is again. So, we are moving beyond introduction. It will still be some preview review of some of your mathematical concepts and some basics of what we mean by image quality. After that, we are good to jump into the first topic of X-ray projection radiography.

Thank you.